DOCUMENT RESUME

ED 261 190 CE 042 346

AUTHOR Glaser, Robert
TITLE The Nature of Expertise. Occasional Paper No. 107.
INSTITUTION Ohio State Univ., Columbus. National Center for Research in Vocational Education.
PUB DATE 85
NOTE 26p.
AVAILABLE FROM National Center Publications, National Center for Research in Vocational Education, 1960 Kenny Road, Columbus, OH 43210-1090 (OC107--$3.00).
PUB TYPE Viewpoints (120) -- Reports - Descriptive (141)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS *Cognitive Development; *Cognitive Structures; *Learning Processes; *Learning Strategies; Memory; Pattern Recognition; Postsecondary Education; *Problem Solving; Secondary Education
IDENTIFIERS *Experts

ABSTRACT

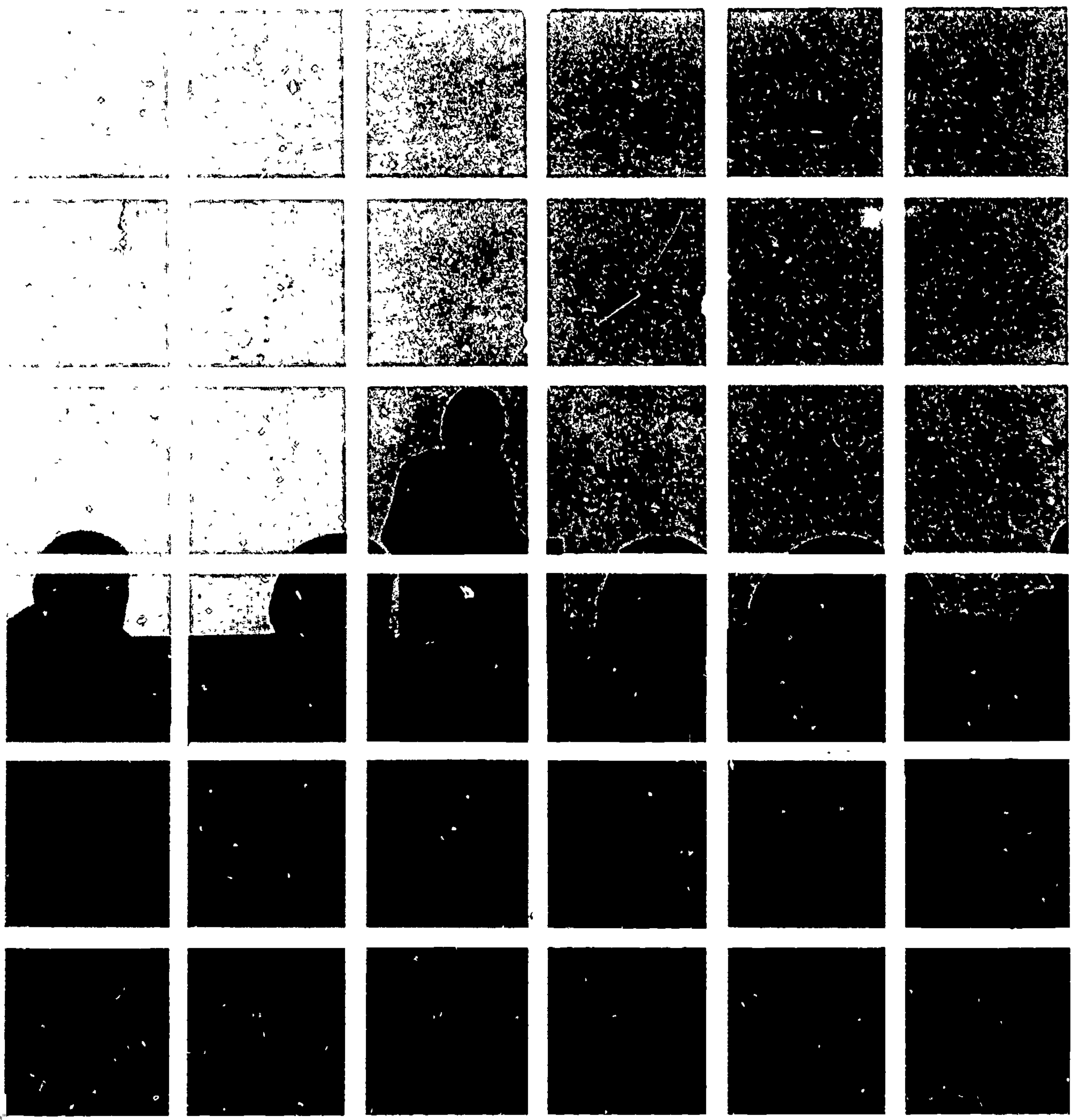
Information-processing students solving problems in the 1960s and 1970s accepted the tradition of early experimental psychology in concentrating primarily on the study of "knowledge-lean" tasks in which competence can usually be acquired over short periods of learning and experience. In recent years, experts have examined knowledge-rich tasks that require hundreds and thousands of hours of learning and experience in an area of study. Investigations of problem solving in knowledge-rich domains show strong interactions between structures of knowledge and cognitive processes. Data and theory in developmental psychology, studies of expert/novice problem solving, and process analyses of high and low scorers on intelligence and aptitude test tasks show that a major component of expertise is seen to be the possession of accessible and usable knowledge. Five generalizations can be made about the nature of expertise: first, there seems to be a continuous development of competence, as experience in a field accumulates; second, expertise seems to be very specific; third, experts develop the ability to perceive large, meaningful patterns; fourth, the knowledge of experts is highly procedural; and fifth, these components of expertise enable fact-access pattern recognition and representational capability that facilitate problem perception, greatly reducing the role of memory search and general processing. Increased understanding of the nature of expertise challenges educators to inquire how it is learned. It seems evident that expertise is acquired when people continually try to confront new situations in terms of what they know. Thus, when teaching beginners, teachers must build from initial knowledge structures. Acquiring expertise is the successive development of procedurally oriented knowledge structures that facilitate the processes of expertise. (KC)

The Nature of Expertise

Robert Glaser

Occasional Paper No. 107

THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY
1960 KENNY ROAD · COLUMBUS, OHIO 43210



THE NATIONAL CENTER MISSION STATEMENT

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Providing information for national planning and policy
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

For further information contact:

Program Information Office
National Center for Research
in Vocational Education
The Ohio State University
1960 Kenny Road
Columbus, Ohio 43210-1090

Telephone: (614) 486-3655 or (800) 848-4815
Cable: CTVOCEDOSU/Columbus, Ohio
Telex: 8104821894

Occasional Paper No. 107

THE NATURE OF EXPERTISE

Robert Glaser
Codirector
Learning Research and
Development Center

The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road
Columbus, OH 43210-1090

1985

FOREWORD

One of the crucial issues in training is what distinguishes a novice from an expert—what mysterious processes convert a beginning learner into a mature performer in a skill or knowledge area. In recent years, the field of cognitive psychology has devoted considerable resources in researching how novices develop into experts, in order to uncover the processes and try to devise a workable theory to drive effective—and more efficient—teaching. As vocational education is a learning enterprise, these concerns about basic skill acquisition and enhancement have important implications for the rapid training (and retraining) and assimilation of skills related to new technologies and to standards of performance concerned with increasing productivity. As such, this paper should be of interest to curriculum developers, instructors, trainers in business and industry, and program planners.

Dr. Robert Glaser is a Professor of Psychology at the University of Pittsburgh and is also the Codirector of the Learning Research and Development Center. He has published close to 200 articles related to the acquisition of expertise in complex domains of knowledge and skill and in the cognitive processes basic to aptitude and intelligence. He has served as a consultant to both national and international governmental associations and commissions, including the President's Subpanel on Science, the Committee on Economic Development of the North American Treaty Organization, the National Science Foundation, UNESCO, and the Ford Foundation. He currently serves on the Board of Trustees of the Human Resources Research Organization, as well as the Executive Committee of the International Association of Applied Psychology and the editorial boards of several scientific journals. He has been a Fellow at the Advanced Study Center for Behavioral Sciences at Palo Alto. Dr. Glaser is also a past President of the American Educational Research Association, and has been awarded a Guggenheim Fellowship.

On behalf of the National Center and The Ohio State University, I am immensely pleased to present Dr. Glaser's address on "The Nature of Expertise," an area of crucial concern to the vocational education community.

Robert E. Taylor
Executive Director
The National Center for Research
in Vocational Education

THE NATURE OF EXPERTISE

Introduction

Information-processing students problem solving in the 1960s and 1970s accepted the tradition of early experimental psychology in concentrating primarily on the study of "knowledge-lean" tasks in which competence can usually be acquired over short periods of learning and experience. Studies of these tasks illuminated the basic information processing capabilities people employ when they behave in situations where they lack any specialized knowledge and skill. The pioneering work of many researchers richly described general heuristic processes (such as means-end analysis, generate and test, and subgoal decomposition), but provided limited insight about the learning and thinking that require a rich structure of domain-specific knowledge that is especially relevant to vocational education.

In recent years, experts have examined knowledge-rich tasks that require hundreds and thousands of hours of learning and experience in an area of study. Studies of expertise have attempted to sharpen this focus by describing contrasts between the performance of novices and experts. The novices in these studies (e.g., intern radiologists, electronics technicians) have engaged in learning over much longer periods than are required for short experimental tasks.

Investigations of problem solving in knowledge-rich domains show strong interactions between structures of knowledge and cognitive processes. The results force us to think about high levels of competence in terms of the interplay between knowledge structure and processing abilities. The data illuminate a critical difference between individuals who display more and less ability in particular domains of knowledge and skill, namely, the possession of rapid access to and efficient utilization of an organized body of conceptual and procedural knowledge.

Data and theory in developmental psychology, studies of expert/novice problem solving, and process analyses of high and low scorers on intelligence and aptitude test tasks show that a major component of expertise is seen to be the possession of this accessible and usable knowledge.

Developmental Studies

As a warm-up exercise (and to introduce a point of view), let me briefly mention some developmental studies with children. In several studies, CHI (Chi 1978; Chi and Koeske 1983) examined recall in children. She contrasted high- and low-knowledge children in chess skill and also children with high and low knowledge of dinosaur categories and features. Her results replicated in significant ways the early chess studies of DeGrott (1965) and of Chase and Simon (1973a, 1973b); high-knowledge individuals showed better memory and encoding performance than those with low knowledge. This superiority was attributed to the influence of knowledge in content areas rather than to the exercise of memory capabilities. Changes in the knowledge base appear to enable sophisticated cognitive performance.

Carey's (in press) studies of animistic thinking in young children trace the emergence of a child's concept of "alive," She documents a change, something like a novice to expert shift, from a knowledge organization centering around human characteristics (a novice point of view) to a knowledge organization centering around the biological functions of living things. Carey makes the point that what can be interpreted as abstract, pervasive changes in a child's reasoning and learning abilities come about as knowledge is gained in a given domain.

The acquisition of content knowledge as a factor in acquiring increasingly sophisticated problem-solving abilities is pointed to in Siegler and Richard's (1982) "rule assessment" studies. They conclude that "knowledge of specific content domains is a crucial dimension of development in its own right and that changes in such knowledge may underlie other changes previously attributed to the growth of capacities and strategies" (p. 930).

Artificial Intelligence

A focus on the structure of knowledge is also apparent in artificial intelligence (AI) systems. In contrast to earlier emphases on general problem-solving techniques, to guide a search for any problem—a power-based strategy—Minsky and Papert (1974) emphasize the role of a knowledge-based emphasis in achieving intelligent thinking. They write:

> The Power strategy seeks a generalized increase in. . .it may look toward extensions of deductive generality, or information retrieval, or search algorithms. . .In each case the improvement sought is. . .independent of the particular data base. The Knowledge strategy sees progress as coming from better ways to express, recognize, and use diverse and particular forms of knowledge. . .It is by no means obvious that very smart people are that way directly because of the superior power of their general methods—as compared with average people—A very intelligent person might be that way because of specific local features of his knowledge-organizing knowledge rather than because of global qualities of his "thinking." (p. 59)

Expert/Novice Problem Solving

The work on problem solving in adult experts and novices has shown fairly consistent findings in quite a variety of domains—chess play, physics problem solving, the performance of architects and electronics technicians, and interpretation of x-rays by skilled radiologists. This work has shown that relations between the structure of a knowledge base and problem-solving processes are mediated through the quality of representation of the problem. This problem representation is constructed by the solver on the basis of domain-related knowledge and the organization of this knowledge. The nature of this organization determines the quality, completeness, and coherence of the internal representation, which in turn determines the efficiency of further thinking.

Expert/novice research suggests that novices' representations are organized around the literal objects and events given explicitly in a problem statement. Experts' knowledge, on the other hand, is organized around inferences about principles and abstractions that subsume these factors. These principles are not apparent in the statement or the surface presentation of the problem. For example, in our studies with mechanics problems, novices classify problems on a surface level, according to the physical properties of a situation—a spring problem or an inclined plane problem. Experts categorize problems at a higher level, in terms of applicable physics principles—a Newton's second law problem, a conservation of energy problem.

In addition, experts know about the application of their knowledge. Their declarative information is tightly bound to conditions and procedures for its use. An intermediate novice may have sufficient knowledge about a problem situation, but lack knowledge of conditions of applicability of this knowledge.

Consider a technical example. From protocols of novices and experts in solving elementary physics problems, we attempted to define the structure of their knowledge in the form of node-link networks (Chi, Glaser, and Rees 1982). The nodes are key terms and physics concepts mentioned by the subjects. The links are unlabeled relations that join the concepts mentioned contiguously in the solver's protocol. The network of a novice's (H.P.) and an expert's (M.G.) elaboration of the concepts of an "inclined plane" problem are shown in figures 1 and 2, respectively. We can view each of these concepts as representing a potential schema; the terms and concepts mentioned in the protocol can be thought of as the variables of the schema. For example, in novice H.P.'s protocol, the inclined plane schema contains numerous variables that can be instantiated, including the angle at which the plane is inclined with respect to the horizontal, whether a block is resting on the plane, and the mass and height of the block. Other variables mentioned by the novice include the surface property of the plane, whether or not it has friction, and, if it does, the coefficients of static and kinetic friction. The novice also discusses possible forces that may act on the block, for example, the drag of a pulley. Also considered is the pertinence of conservation of energy, but this was not elicited as a part of a solution procedure applicable to a configuration involving an inclined plane, as is the case with the expert. Hence, in general, one could say that the inclined plane schema that the novice possesses is quite rich. The novice knows precisely what variables ought to be specified, and also has default values for some of them. For example, if friction is not mentioned, then friction should probably be ignored. Hence, with a simple specification that the problem is one involving an inclined plane, the novice can deduce accurately what the key components and entities are (i.e., friction) that such a problem would entail.

However, the casual reference to the underlying physics principle, conservation of energy, given by the novice contrasts markedly with the expert's protocol (figure 2). The expert immediately makes a call or two principles that take the status of procedures, the conservation of energy principle and the force law. (In Greeno and Riley's [1981] terminology, they would be considered calls to action schemata.) We characterize them as procedures (thus differentiating them from the way the novice mentioned a principle) because the expert, after mentioning the force law, continues to elaborate on the condition of applicability of the procedure and then provides formulas for two of the conditions (enclosed in dashed rectangles in figure 2). After elaborating on the principles and the conditions of applicability of one principle to inclined plane problems (depicted in the top half of figure 2), expert M.G. continued the protocol with descriptions of the structural or surface features of inclined plane problems, much like the descriptions provided by novice H.P. The knowledge common to subjects of both skill groups pertains to the physical configuration and its properties, but the expert has additional knowledge relevant to the solution procedures based on major physics laws.

Another way of viewing the difference between the novice's and expert's elaborations of the inclined plane is to look at Rumelhart's (1981) description of schemata of inactive objects. Here, an inclined plane is seen by the novice as an inactive object, so that it evokes not actions or event sequences, but spatial relationships and descriptions of the configuration and its properties. Experts, on the other hand, view an inclined plane in the context of potential solution procedures, that is, not as an object, but more as an entity that may serve a particular function.

As in the developmental studies, the problem-solving "difficulties" of novices can be attributed largely to the nature of their knowledge bases, and much less to the limitations of their processing

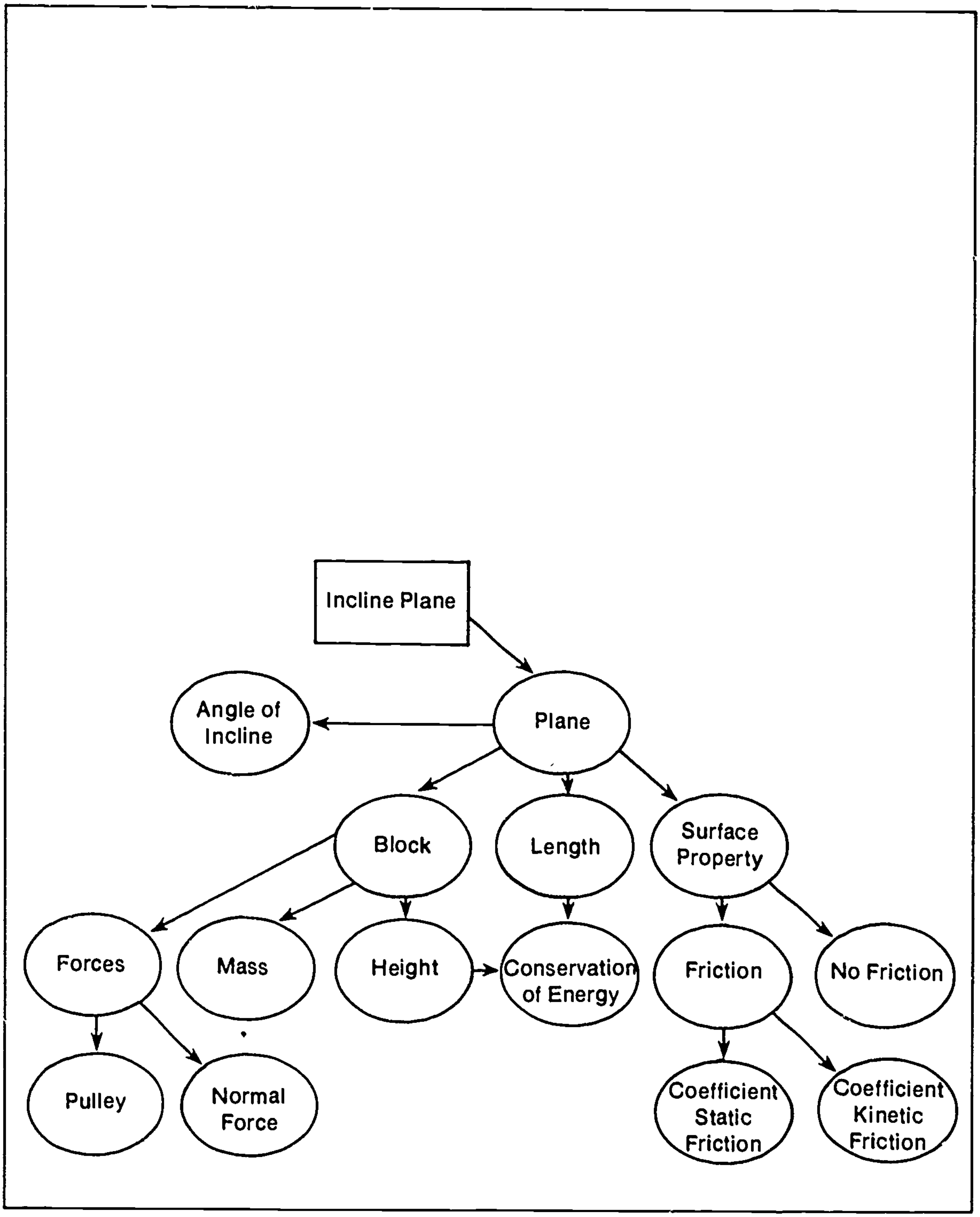


Figure 1. Network representation of novice H.P.'s schema of an inclined plane

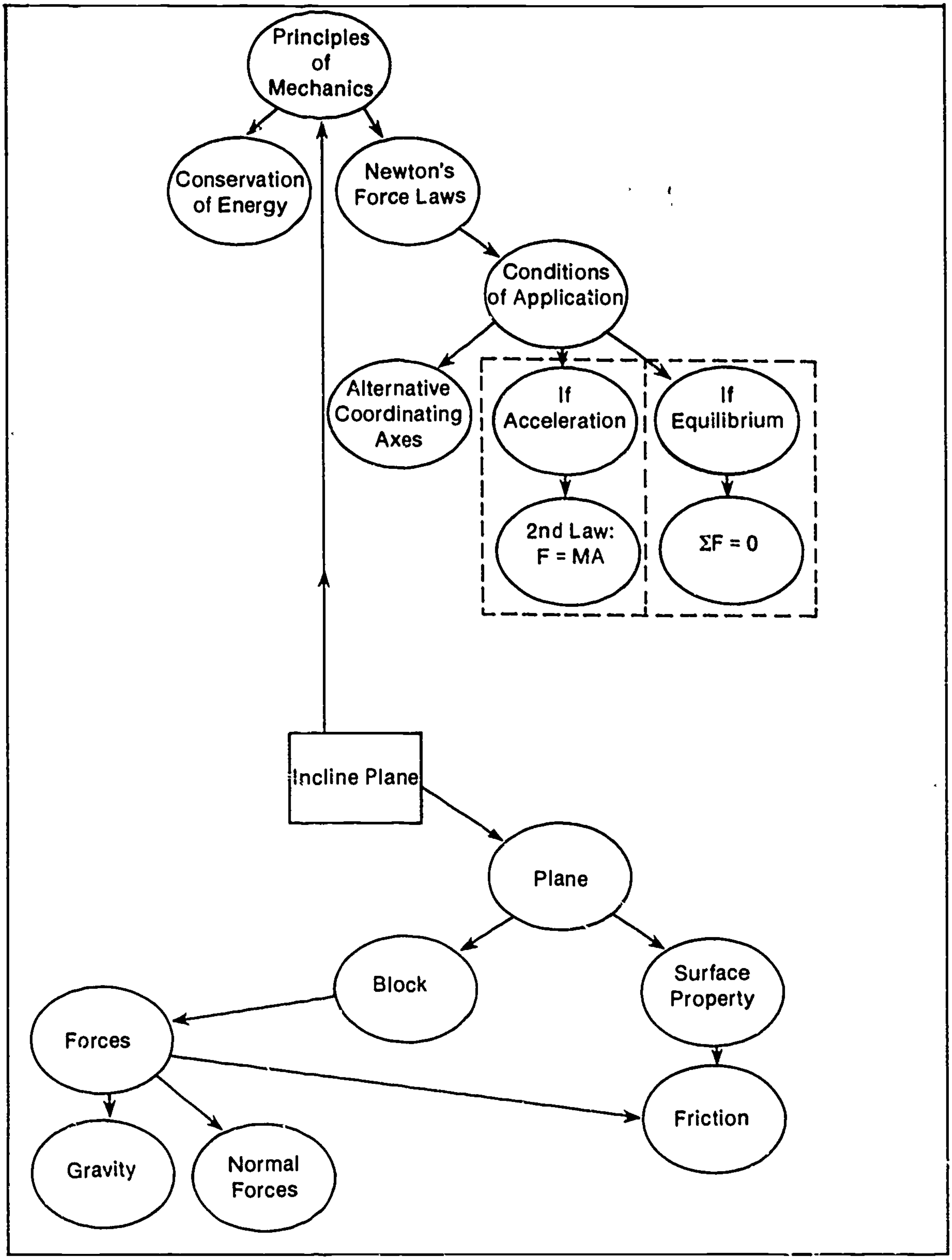


Figure 2. Network representation of expert M.G.'s schema of an inclined plane

capabilities, such as their inability to use general problem-solving heuristics. Novices do show effective use of heuristics; the limitations of their thinking are derived from their inability to infer further knowledge from the literal cues in a problem situation. These inferences are necessarily generated in the context of a knowledge structure that experts have acquired.

In general, study of problem solving by highly competent people in rich knowledge domains provides a glimpse of the power of human thinking to use a large knowledge system in an efficient and automatic manner—particularly in ways that minimize reliance on the search heuristics identified in studies of knowledge-lean problems. Thus, a significant focus for understanding expertise is identifying the characteristics and influence of organized knowledge structures that are acquired over long periods of time.

Aptitude Test Performance

Consider another converging area: process analyses of aptitude and intelligence test tasks performed by high- and low-scoring individuals. The evidence in this area comes from studies carried out by Hunt, Frost, and Lunneborg (1973), Robert Sternberg (1977b), and Pellegrino and Glaser (1982). My interpretation of several components of performance that differentiate high- and low-scoring individuals is the following: one component appears to involve rapid access to and management of working memory; the next two components appear to involve specific knowledge. The first is conceptual knowledge of the item content. Low-scoring individuals with less available knowledge encode at surface feature levels rather than at levels of generalizable concepts; this limits their inferential ability. The second component is knowledge of the solution procedures required for solving a particular task form, such as analogical reasoning or induction items. Low-scoring individuals display a weak knowledge of procedural constraints that results in procedural bugs, and an inability to recover the goals of an analogy problem when they need to pursue subgoals of the task. This weak knowledge of procedural constraints sometimes allows them to turn a problem into an easier one to solve, such as a word association task. Such acquired knowledge, then, is suggested as a significant aspect of skillful aptitude test performance.

Schemata and Theories

The organizations of knowledge that are developed by experts can be thought of in terms of schemata or theories of knowledge. I define a schema here as a modifiable information structure that represents generic structures of concepts stored in memory. Schemata represent knowledge that we experience, such as interrelationships between objects, situations, and events that occur. In this sense, schemata are prototypes in memory of frequently experienced situations that individuals use to integrate and interpret instances of related knowledge. Schema theory assumes that there are schemata for recurrent situations, and that these schemata enable people to construct interpretations, representations, and perceptions of situations.

If we think of a schema as a theory or internal model that is used, matched, and tested by individuals to instantiate the situations they encounter, like a scientific theory, it is a source of representation and prediction. It enables individuals to impute meaning to a situation and to make inferences from information. As is the case for a scientific theory, if it fails to account for certain aspects of one's observations, it leads to learning that can modify or replace the theory. As a representation of a problem situation, it is accompanied by rules for solution of the problem.

Self-regulation and General Skills

To temper my emphasis on structures of knowledge, I now point out that experts in various domains show self-regulatory or metacognitive capabilities that are not present in less mature or less experienced learners. These skills include knowing what one knows and doesn't know, planning ahead, efficiently apportioning one's time and attentional resources, and monitoring and editing one's efforts to solve a problem. To a large extent, I suspect that these self-regulatory activities are specific to a domain of knowledge in experts. Where they appear to be generalized competencies (i.e., in "generally intelligent" individuals), my hypothesis is that they become abstracted strategies after individuals use them in several fields of knowledge.

Perhaps widely competent children and adults, because of intensive exposure to different domains, employ skills that evolve as generalized cognitive processes. As general methods, however, these may be a small party of the intelligent performance shown by experts in specific fields of knowledge where they rapidly access acquired schemata and procedures. General processes may be important when an individual is confronted with problems in unfamiliar areas. However, future research may show that generalizable and transferable expertise lies in an ability to use familiar domains of knowledge for analogical and metaphorical thinking about new domains.

Generalizations

Five generalizations can be made about the nature of expertise based upon information presented here in this paper. First, there seems to be a continuous development of competence, as experience in a field accumulates. Eventual declines in competence may be the result of factors in the conditions of experience. Competence may be limited by the environment in which it is exercised. People may attain a level of competence only insofar as it is necessary to carry out the activities or to solve problems at the given level of complexity presented. Situations that extend competence may be less forthcoming as experts settle into their working situations.

Second, expertise seems to be very specific. Expertise in one domain is no guarantee of expertise in other areas. It may be, however, that certain task domains are more generalizable than others, so that adults who are experts in applied mathematics or aesthetic design, or children when they learn measurement and number concepts, have forms of transferable expertise.

Third, experts develop the ability to perceive large, meaningful patterns. This pattern recognition occurs so rapidly that it takes on the character of "intuition." In contrast, the patterns novices recognize are smaller, less articulated, more literal and surface oriented, and much less related to inferences and abstracted principles. The extraordinary representational ability of experts appears to depend on the nature and organization of knowledge existing in memory. The fact that an expert has a more coherent, complete, functional, and principled representation of knowledge than a novice implies an initial understanding of a problem that leads more easily to correct procedures and solutions.

Fourth, the knowledge of experts is highly procedural. Concepts are bound to procedures for their application and to conditions under which these procedures are useful. The functional knowledge of experts is related strongly to their knowledge of the goal structure of a problem. Experts and novices may be equally competent at recalling small, specific items of domain-related information. But high-knowledge individuals are much better at relating these events in cause and effect sequences that relate to the goal and subgoals of problem solution.

Fifth, these components of expertise enable fact-access pattern recognition and representational capability that facilitate problem perception, greatly reducing the role of memory search and general processing. Novices, on the other hand, display a good deal of search and processing of a general nature. Their perceptions are highly literal and qualitatively different than representations of experts.

This picture of expertise is biased by the highly structured domains in which it has been studied, and by the demands of situations in which cognitive expertise is required. How do experts solve problems in "ill-structured" domains? How do different experiences lead to different forms of expertise? (Hatano and Inagaki 1983) distinguish between routine (or conventional) expertise and adaptive expertise. Routine experts are outstanding in terms of speed, accuracy, and automaticity of performance, and construct mental models convenient for performing their tasks, but they lack adaptability to new problems. Probably, repeated application of a procedure with little variation leads to routine expertise. Adaptive expertise requires variation and is encouraged by playful situations and in cultures where understanding is valued along with efficient performance. Hatano (ibid) speculates about how expertise might develop in an efficiency-oriented as compared with an understanding-oriented environment.

A Pride of Propositions

I will summarize up my thoughts about expertise in a set of propositions. These statements represent conclusions from research and occasional broader inferences and speculations.

1. Expertise is developed over hundreds and thousands of hours of learning and experience, and continues to develop. Studies have been carried on in many domains of work: chess-masters, scientists solving problems, radiologists, skilled technicians, abacus champions, athletes, architecture planners, livestock judges, and dairy workers (Chi, Glaser, and Rees 1982; Chi, Glaser, and Farr in press).

2. In the course of acquiring expertise, plateaus and nonmonotoniticies of development are observed that appear to indicate shifts in understanding and stabilizations of automaticity. Karmiloff-Smith (1984), Strauss and Stavy (1982), and Lesgold (1984) have suggested that novices and experts perform better than intermediates on problems that can be solved by surface-level representations.

3. Experts and novices work with similar capacity for processing; the outstanding performance of experts is derived from how their knowledge is structured for processing.

4. Expert representations of problems and situations are qualitatively different than novice representations. In the course of developing expertise, problem representation changes from surface representations to inferred problem descriptions, to principled (and proceduralized) categorizations.

5. Expert representations (and schema instantiations) are like fast-access pattern recognitions that reduce processing load and the need for general search heuristics.

6. The representations of experts have actionable meaning; the knowledge of an expert is highly proceduralized and abound to conditions of the applicability of their knowledge.

7. In some domains, experts are "opportunistic planners"; new problem features result in changed problem representation; they show fast access to multiple possible interpretations; novices are less flexible (Lesgold et al. 1981).

8. Experts can be disarmed by random (or meaningless) patterns and lose their great perceptual ability (e.g., with a scrambled chessboard, experts and novices do equally poorly).

9. Experts are schema specialized and these schemata drive their performance. (Experts impose a structure on a noisy x-ray; novices are misled by this noise.)

10. Experts are goal driven: given a complex goal, they will represent the problem accordingly; given simple goals, they will think only as deeply as necessary.

11. Experts display specific domain intelligence, not necessarily general intelligence.

12. Novices display good use of general heuristic problem-solving processes (generate and test, means-end analysis, subgoal decomposition); experts use them primarily in unfamiliar situations.

13. Experts may be slower than novices in initial problem encoding but are overall faster problem solvers (e.g., analogical reasoning test items, see Sternberg [1977]).

14. The development of expertise is subject to task demands and the "social structure" of the job situation; the cognitive models experts acquire are constrained by task requirements (Scribner 1984a, 1984b).

15. Expertise in some knowledge domains may be more generalizable (broadly applicable) than other domains (e.g., measurement concepts, number concepts, and arithmetic problem-solving schema, see Carey [in press]).

16. Experts develop automaticity (unconscious processing), particularly of "basic operations," so that working memory is available for necessary conscious processing (e.g., efficient encoding processes in expert reading comprehenders, see Perfetti and Lesgold [1979]).

17. The experts' understanding may occur after extended practice with procedural skills (Karmiloff-Smith 1984; Strauss and Stavy 1982).

18. In solving ill-structured problems, experts employ relatively general methods of problem decomposition, subgoal conversion, and single factor analysis; their thinking is less immediately driven by principles and procedural aspects of their specific knowledge structures.

19. In ill-structured domains, experts work from their memory of an issue's history to represent problems and devise arguments for alternative solutions.

20. Experts develop skilled self-regulatory processes such as solution monitoring, allocation of attention, and sensitivity to informational feedback (Brown 1978; Gitomer and Glaser in press).

21. Expertise can be "routine" or "adaptive and reflective," depending upon the variety of experience and the culture in which it develops (Hatano and Inagaki 1983).

22. Expert knowledge is not inert; it is highly proceduralized, conditioned, and compiled (Anderson 1983).

23. Super experts may develop generalizable abilities through the use of mapping and analogy from their own domain to others (Gentner and Gentner 1983).

24. General thinking and problem-solving skills may develop in the course of shifting between many domains, so that the cognitive processes involved become decontextualized (Glaser 1984).

Conclusion

Increased understanding of the nature of expertise challenges us to inquire how it is learned. It seems evident that expertise is acquired when people continually try to confront new situations in terms of what they know. Increasing ability to solve problems and generate new information is fostered by available knowledge that can be modified and restructured. Thus, when teaching beginners, we must build from initial knowledge structures. This might be accomplished by assessing and using relevant prior knowledge, or by providing obvious organizational schemes or temporary models as scaffolds for new information. These temporary "pedagogical theories" are regularly devised by ingenious instructors and could be incorporated more systematically into instruction. Such structures, when they are interrogated, instantiated, or falsified by novices in the course of learning and experience, lead to organizations of knowledge that are the basis for the more complete schemata of experts. Acquiring expertise is the successive development of procedurally oriented knowledge structures that facilitate the processes of expertise.

QUESTIONS AND ANSWERS

Robert Glaser

Question: I want to know if your notions about developing expertise are useful for vocational instruction. You've talked about the development of knowledge, but how is this applied to learning skills—how to *do* things?

I think that in the process of carrying out skills, we can consider both skills and knowing things as forms of knowledge. Let's call one procedural knowledge and one declarative knowledge. In carrying out the "doing" skills, it seems to me that one has to have some idea about those skills. That is, if you do it this way, X will happen. Suppose another person does it another way; would that be wrong or right? Both people have some model of the performance of the skills.

Even if a skill is a highly manipulative kind of performance, it is not done in a mindless way. It is done on the basis of some idea that if you do this, this is going to happen, or on the basis of realizing that you can't carry out this procedure in the context of these conditions. There are ways in which people using skills think about these things.

There are studies in which people are taught procedural skills. Sometimes they are taught just a list of procedural skills, but sometimes they are taught with some sort of up-front model of how those skills are organized. This latter approach gives the subjects an advanced organizer, some idea of what will probably happen when they try to solve a problem or do something in a certain way.

Teaching procedural skills using some sort of model seems to result in better retention of those skills, and in better prediction of what happens if you make a wrong move. It is not as clear as in the case of more academic knowledge or more procedural knowledge, but there is no doubt that when people perform actions, they have some kind of model in mind that allows them to predict what they are doing. It also allows them to stop if they see something incongruous developing in the situation.

Question: Isn't it just as useful to let students learn the procedures of a skill by trial and error, without using a model?

Oh, no! My temptation is always to allow the steps to be placed in some kind of an organizational structure, because the only way we can remember things is by having some bucket in which to put them. And so you've got to give them some kind of structure. It may be a skimpy bucket to start with, but as you put more things in it, the bits become attached; they become a sort of network. And then you can hang things on the network.

Question: How would you relate learning theory ideas, such as assimilation and accommodation, to your ideas about developing expertise? Also, how do you think people actually develop schemata when learning vocational skills?

If you look at how developmental psychologists view the knowledge elaborations of children, you know that instructors have a lot to teach. Learning theorists believe that as structures in knowledge become more complex, students who have not assimilated those structures become unable to do more things because the knowledge becomes more abstract. The notions of assimilation and accommodation seem very irrelevant to the learning of new knowledge structures, so I would tend to think about it in those terms.

The question of schemata acquisition—how one learns those things, and how they develop—is currently a topic in research, and it would be terrific to look at some of that development in terms of technical and vocational tasks. Such tasks seem to have a more finite domain than do physics problems or radiology problems, but that is probably deluding. Every time we get into a domain we think is finite, we find that it becomes so complex. I'm sure you're all aware of that.

Question: How do you distinguish a person who is a superior recognizer from one who is a deep thinker? And, is one really better than the other?

I think that becoming a superior recognizer leads to becoming a deep thinker, because as you begin to recognize the bigger implications of a situation, you probably begin to think more deeply. In a sense, the richer your knowledge structure is, the more efficient your thinking processes become. If you're making distinctions between knowledge and process, the more knowledge you have, the more you can remember.

People used to think that experts remember more because they have better memories, or even better IQs. But people who are experts in a particular subject matter have better memories only in that subject matter. This is because they have organized their knowledge into larger, more accessible "chunks." When they look at a situation, they see a large structure in it, and in their minds that structure is all tied up with little pieces of knowledge and procedures. So one answer to your question is that being a better recognizer means you bring a schema to a situation that allows you to see underlying principles rather than surface features. This also influences your problem-solving procedures.

This situation is most clear in research on artificial intelligence. To make computers smarter, you have to teach them to know how to do some of the abstract things that humans do. Initial work in computers concentrated on the heuristics of search schemata. Some of the questions then were, how do you develop faster research capabilities? How do you develop faster forms of searching the computer? That means you need faster processes; you want more computational power.

Now, researchers in artificial intelligence are saying, "What we want to build into the computer are more structured knowledge networks." They have recognized that if you want to play chess with a computer—a computer that's going to spend all its time searching its memory for a duplicate situation—it is not going to be as efficient as a computer that has structures of knowledge that enable it to recognize the nature of the situation. Researchers today are attempting to build large, connected knowledge networks into the computer.

People who seem to be more intelligent may appear so because they have richer knowledge structures, not because they think faster. That's the point I was making—that superior recognizers and deep thinkers may not be all that different. Some people are probably born to think faster than others, but it's certainly true that knowledge structures enable you to remember better and so think faster. We have done experiments, just for fun, in which our subjects were people with expert knowledge in baseball, and with other people who were avid baseball fans but whose knowledge about the game was average for fans. The average fans listened to a baseball game and their recall of the game was phenomenal. They not only remembered the players, but they also remembered the interactions between them, all these subtleties of baseball. The experts had much less specific memory—they remembered much more about who was selling popcorn than they did about the specific game. But their structure of knowledge about baseball itself was very powerful.

I think this has strong implications for instruction, because it does not mean that we should be teaching students to think better or to develop more abstract powers, but that we should be teaching them to confront knowledge by knowing that process, and to make predictions from the new knowledge that these processes will develop.

Question: Do you feel that the notion of field dependence and field independence meshes with your findings?

It's probably quite relevant, but I don't know what we would learn if we did a field independence/dependence test on experts versus novices. I would expect that the experts become more field independent. But I don't know which comes first—the chicken or the egg.

Question: What do you think would be the influence of learning styles on the development of expertise along the lines you discussed?

That's a good question because we don't know what "learning styles" means. We have very qualitative definitions of it, but it's a difficult concept to pin down. How would the concept of learning styles fit in the context of the kind of instruction I talked about, the interrogation and tutorial approach?

I would like to study the differences between students who are the good learners and students who are poor learners and try to understand why some of them do better than others. Is it that the good learners have attended better to a situation? Is it that they've learned to monitor their work better? This notion of monitoring relates to a field of study in cognitive psychology, called metacognition, that is based on the fact that good learners have certain motor characteristics of learning. That is, they look at their work, they anticipate what they are going to do on a problem before they do it, they plan ahead, and when they do a problem, they check on it. They have all these metacharacteristics.

I think that is a kind of a learning style. Those kinds of performance are learned. They're very characteristic of mature learners. In immature learners, you don't find that those properties are well learned or well exercised. The question of mature learning styles is like the old question of study skills, that is, do good learners check their work? We have always tried to teach those as skills, but we've never tried teaching them in the context of exercising your knowledge so that you get feedback from your knowledge in a specific domain. I think that's the trick to exercise—learning to use a self-checking behavior. This sort of self-regulatory behavior—the way in which mature individuals regulate their own learning—is really the learning style that I would hunt for.

Question: If the National Center were to mount an effort here to tie into your research program and extend its specific applications to our arena of education, what might be the nature of that approach? What would you suggest as the initial take-off point?

Our people at the Learning Research and Development Center (LRDC) are interested in studying technical skills, so we're interested in how people learn basic electronics, for example. We have seen that the mental models that many people have when they begin to learn basic electronics theory seem to preclude their learning the material very successfully. One way the National Center and LRDC could cooperate would be for you to share your knowledge of interesting technical tasks. What we would then do would be to use that information to conduct an in-depth study of some of those tasks with the population that has to learn them.

Question: Does task analysis have useful implications for training people to develop expertise in technical skills?

In the traditional forms of task analyses, you break a task up into tiny pieces so you can understand its components. Then, when the task is laid out, the temptation is to teach those tiny pieces and build the task up again. There's a temptation to say that there has been talk abou, ,ask analysis versus cognitive task analysis in which you look not only at the components of what you are doing but also at some of the schemata people learn as they do them. So for example, there's been a lot of work by Jim Greeno (1981) on word problems, which are particularly difficult for children in school. Greeno has found that one kind of knowledge children in school learn in doing word problems is that you know this is the problem and that if has such-and-such word always in it, it always means plus, and so forth. They also learn that word problems have certain structures. Some of the word problems involve exchange. Others are move problems, where you move one object or amount to another. Greeno says that what children identify, in addition to the arithmetic operations involved in the problem, is qualitative characterization of the problem. That is, they learn to recognize that this is an exchange problem, or that this is a move problem. Characterization of the problem together with their skill in arithmetic is what really helps them solve it.

There's a study carried out on word problems that involve solving a river problem—a problem in which you go one way and the current goes another. Once the students can categorize the problem (what you're teaching them is a form of cognitive categorization), they can place it in their knowledge schemata and say it's this kind of problem. That is, they can say, "It's a river problem, and I know river problems are solved this way." So they learn via employing a kind of categorization.

Relating task analysis to take advantage of these findings will probably mean, for analysis of tasks in a job, first looking at the overhead operations, than also looking at the kind of structure or categorization or intuitive knowledge that the workers build up, so that the two can support each other.

REFERENCES

Anderson, J.R. *The Architecture of Cognition*. Cambridge: Harvard University Press, 1983.

Brown, A.L. "Knowing When, Where, and How to Remember: A Problem of Metacognition." Vol 1, *Advances in Instructional Psychology*, edited by Robert Glaser. Hillsdale, NJ: Erlbaum, 1978.

Carey, S. "Are Children Fundamentally Different Kinds of Thinkers and Learners than Adults?" Vol. 2, *Thinking and Learning Skills: Current Research and Open Questions*, edited by S.F. Chipman, J.W. Segal, and R. Glaser. Hillsdale, NJ: Erlbaum, in press.

Chase, W.G., and Simon, H.A. "Perceptions in Chess." *Cognitive Psychology*. 4 (1973a) 55-81.

———. "The Mind's Eye in Chess." *Visual Information Processing*, edited by W.G. Chase. New York: Academic Press, 1973b.

Chi, M.T.H. "Knowledge Structures and Memory Development," Vol 1, *Children's Thinking: What Develops?* Hillsdale, NJ: Erlbaum, 1978.

Chi, M.T.H.; Glaser, R.; and Farr, M. *The Nature of Expertise*. Hillsdale, NJ: Erlbaum, In press.

Chi, M.T.H.; Glaser, R.; and Rees, E. "Expertise in Problem Solving." Vol. 1, *Advances in the Psychology of Human Intelligence*. edited by R. Sternberg. Hillsdale, NJ: Erlbaum, 1982.

Chi, M.T.H., and Koeske, R.D. "Network Representation of a Child's Dinosaur Knowledge." *Developmental Psychology* 19 (1983): 29-39.

de Groot, A. *Thought and Choice in Chess*. The Hague: Mouton, 1965.

Gentner, D., and Gentner, D.R. "Flowing Waters of Teeming Crowds: Mental Models in Electricity." In *Mental Models*, edited by D. Gentner and A.L. Stevens. Hillsdale, NJ: Lawrence Erlbaum Associates, 1983.

Gitomer, D.H., and Glaser, R. "Knowledge, Self-regulation and Instruction." Vol. 3, *Aptitude, Learning, and Instruction*, edited by R.E. Snow and M.J. Farr, Hillsdale, NJ: Erlbaum, In press.

Glaser, R. "Education and Thinking." *American Psychologist*, 39 (1), 1984: 93-104.

Greeno, J.G., and Riley, M.S. "Processses and Development of Understanding." *Learning by Thinking*, edited by F.E. Weinert and R. Kluwe. Stuttgart, West Germany: Kohlhammer, 1981.

Hatano, G., and Inagaki, K. *Two Courses of Expertise*. Paper presented at the Conference on Child Development in Japan and the United States, Stanford, California, April, 1983.

Hunt, E. "Mechanics of Verbal Ability." *Psychological Review* 85 (1983): 109-130.

Hunt, E.; Frost, N.; and Lunneborg, C. "Individual Differences in Cognition: A New Approach to Intelligence." Vol. 7, *The Psychology of Learning and Motivation* edited by G.H. Bower. New York: Academic Press, 1973.

Karmiloff-Smith, A. *The Human Capacity for Multiple Representation and its Relevance to Developmental Change*. Paper presented at the conference of the National Academy of Education, Lidingo, Sweden, June 1984.

Lesgold, A.M. "Acquiring Expertise." *Tutorials in Learning and Memory: Essays in Honor of Gordon Bower*, edited by J.R. Anderson and S.M. Kosslyn. San Francisco: W.H. Freeman, 1984.

Lesgold, A.M.; Feltovich, P.J.; Glaser, R.; and Wang, Y. *The Acquisition of Perceptual Diagnostic Skill in Radiology*. Technical Report PDS-1. Pittsburgh: University of Pittsburgh, Learning Research and Develpment Center, 1981.

Minsky, M., and Papert, S. *Artifical Intelligence*. Condon Lectures, Oregon State System of Higher Education, Eugene, Oregon, 1974.

Pellegrino, J.W., and Glaser, R. "Analyzing Aptitudes for Learning: Inductive Reasoning." Vol. 2, *Advances in Instructional Psychology* edited by R. Glaser. Hillsdale, NJ: Erlbaum, 1982.

Perfetti, C.A., and Lesgold, A.M. "Coding and Comprehension in Skilled Reading." *Theory and Practice of Early Reading*, edited by L.B. Resnick and P. Weaver. Hillsdale, NJ: Erlbaum, 1979.

Rumelhart, D.E. "Schemata: The Building Blocks of Cognition." *Theoretical Issues in Reading Comprehension*, edited by R. Spiro, B. Bruce, and W. Brewer. Hillsdale, NJ: Erlbaum, 1981.

Scribner, S. "Cognitive Studies of Work." *Quarterly Newsletter of the Laboratory of Comparative Human Cognition*, 6 (1984a): 1-2.

———. "Studying Working Intelligence." *Everyday Cognition: Its Development in Social Context*, edited by B. Rogoff and J. Lave. Cambridge: Harvard University Press, 1984b.

Sielger, R.S., and Richards, D.D. "The Development of Intelligence." *Handbook of Human Intelligence*, edited by R.J. Sternberg. Cambridge, England: Cambridge University Press, 1982.

Sternberg, R. *Intelligence, Information Processing, and Analogical Reasoning: The Componential Analysis of Human Abilities*. Hillsdale, NJ: Erlbaum, 1977a.

———. "Component Processes in Analogical Reasoning." *Psychological Review* 84 (1977b): 353-378.

Strauss, S., and Stavy, R. "U-shaped Behavioral Growth: Implications for Theories of Development." Vol. 6, *Review of Child Development Research* edited by W.W. Hartup. Chicago: University of Chicago Press, 1982.

LEADERSHIP SERIES IN VOCATIONAL AND CAREER EDUCATION

Apker, Wesley. ***Policy Issues in Interrelating Vocational Education and CETA***,1979 (OC 56—$1.90).

Baker, Eva L. ***New Directions in Evaluation Research: Implications for Vocational Education***, 1979 (OC 55—$1.90).

Bienstock, Herbert. ***New and Emerging Occupations: Fact or Fancy***, 1981 (OC 77—$1.90).

Broudy, Harry S. ***Toward a Theory of Vocational Education***, 1981 (OC 73—$1.90).

Campbell, Anne. ***Vocational Education in an Information Age: Society at Risk?***, 1984 (OC 99—$3.00).

Carnevale, Anthony P. ***The Real Supply-Side Economics***, 1982 (OC 80—$1.90).

Clark, David L. ***Research and Development Productivity in Educational Organizations***, 1978 (OC 41—$2.20).

Cohen, Wilbur J. ***Needed Federal Policy in Education for Century III***, 1977 (OC 24—$1.90).

Craig, Paul G. ***Structural Changes in the Economy and Future Job Prospects***, 1983 (OC 92—$2.50).

Daggett, Willard R. ***Strategic Vision and Planning: Keys to Educational Improvement***, 1984 (OC 100—$3.00).

Day, Sherman. ***Education and Training in the Criminal Justice System: Implications for Vocational Education Research and Development***, 1979 (OC 52—$1.90).

Delacruz, Joseph B. ***Educational Programs for Native Americans: Implications for Vocational Education Research and Development***, 1978 (OC 40—$1.90).

Delker, Paul V. ***Adult Education—1980 and Beyond: Implications for Research and Development***, 1979 (OC 59—$1.90).

Dunham, Daniel B. ***Vocational Education: Policies, Issues, and Politics in the 1980s***, 1980 (OC 65—$2.20).

Edwards, Kenneth R. ***The Perspective of Organized Labor on Improving America's Productivity***, 1983 (OC 89—$2.50).

Elliman, Peter J. ***Critical Issues in Vocational Education: An Industrialist's View***, 1983 (OC 95—$2.50).

Ellis, John. ***Vocational Education and Federal Priorities***, 1978 (OC 47—$1.90).

Ellis, Mary L. ***Vocational Education: The Future Is Now***, 1978 (OC 37—$1.90).

Emmerij, Louis. ***National Strategies for Coping With Unemployment: An International Perspective***, 1981 (OC 69—$1.90).

Etzioni, Amitai. ***Reindustrialization and Vocational Education***, 1981 (OC 76—$1.75).

Evans, Rupert E. ***Vocational Education and Reindustrialization***, 1981 (OC 75—$1.90).

Feldman, Marvin. ***Work, Employment, and the New Economics***, 1981 (OC 70—$2.20).

Field, Ronald H. ***State Legislative Perceptions of Vocational Education***, 1984 (OC 102—$2.75).

Frey, Donald N. ***The Economy, Productivity, and Training—A CEO's View***, 1983 (OC 88—$2.25).

Ganzglass, Evelyn. ***The Knowledge Development Plan of the Office of Youth Programs: Implications for Vocational Education Research and Development***, 1980 (OC 63—$2.20).

Gideonse, Hendrik. ***A Model for Educational Research and Development: 1985***, 1978 (OC 44—$2.20).

Glaser, Robert. ***The Nature of Expertise***, 1985 (OC 107—$3.00).

Glover, Robert W. ***Apprenticeship in the United States: Implications for Vocational Education Research and Development***, 1980 (OC 66—$1.90).

Guba, Egon G. ***The Paradigm Revolution in Inquiry: Implications for Vocational Research and Development***, 1981 (OC 79—$2.80).

Halperin, Samuel. ***Emerging Educational Policy Issues in the Federal City: A Report from Washington***, 1978 (OC 42—$2.20).

Hampson, Keith. ***The Relationship of School and Work: A British Perspective***, 1979 (OC 57—$1.90).

Hampson, Keith. ***Trends in Manpower and Educational Development: A British Perspective***, 1985 (OC 104—$2.75).

Harman, David. ***Adult Education in the United States: Its Scope, Nature, and Future Direction***, 1985 (OC 105—$2.75).

Hemmings, Madeleine B. ***Next Steps in Public-Private Partnerships***, 1984 (OC 103—$3.00).

Herr, Edwin L. ***Work Focused Guidance for Youth in Transition: Some Implications for Vocational Education Research and Development***, 1978 (OC 43—$2.20).

Hicks, Laurabeth L. ***Programs of Guidance and Counseling Becoming of Age: Implications for Vocational Education R&D***, 1977 (OC 25—$1.75).

Hopkins, Charles O. ***A National Prospectus on Vocational Education: Its Impact on Research and Leadership Development***, 1982 (OC 85—$2.25).

Jennings, John F. and Radcliffe, Charles W. ***Commentary on Legislation Affecting Vocational Education Research and Development***, 1977 (OC 27—$1.90).

Knutton, Harry. ***Vocational Education for a Changing Society***, 1982 (OC 81—$2.20).

Kolstoe, Oliver P. ***Implications of Research Findings on Vocational and Career Education for the Mentally Handicapped***, 1977 (OC 33—$1.90).

Kruger, Daniel H. ***Occupational Preparation Programs: Implications for Vocational Education***, 1977 (OC 31—$1.90).

Lecht, Leonard A. ***Vocational Education as a Participant in the Economic Development Enterprise: Policy Options for the Decade Ahead***, 1981 (OC 74—$2.20).

Levitan, Sar A. ***The Unemployment Numbers Is the Message***, 1977 (OC 38—$1.90).

Lindeman, Anne. ***State Concerns in the Future Development of Vocational Education***, 1984 (OC 98—$3.00).

Lloyd, Kent. ***The Federal Perspective on Vocational Education's Role in Economic Revitalization and Productivity***, 1983, (OC 91—$2.50).

Loose, Gert. ***Towards a Cross-National Model for Cooperation in Vocational Education: Implications for Research and Development***, 1982, (OC 87—$3.25).

Lund, Duane R. ***The Role of Vocational Education in the Economic Development of Rural Areas: Implications for Research and Development***, 1980 (OC 62—$2.20).

McCage, Ronald D. ***The Development of a Comprehensive State Capacity for Program Improvement***, 1978 (OC 34—$1.75).

McCune, Shirley D. ***The Organized Teaching Profession and R&D***, 1977 (OC 29—$1.90).

Martin, Edwin. ***New Directions in Vocational Education for the Handicapped: Implications for Research and Development***, 1978 (OC 35—$1.75).

Miller, Edward D. ***The Role of Student Organizations in Vocational Education***, 1983 (OC 94—$2.25).

Miller, Thomas W. ***The Business and Industry Perspective on U.S. Productivity: Implications for Vocational Education***, 1982 (OC 82—$2.50).

Moody, Tom. ***Vocational Education, CETA, and Youth Unemployment: Meeting the Needs of Inner City Youth***, 1979 (OC 50—$1.75).

Musick, Craig D. ***Problems and Issues in Industry-Sponsored Vocational Programs: Implications for Research and Development***, 1980 (OC 67—$2.20).

Parnell, Dale. ***A National Human Resource Development Policy: The Role of Postsecondary Vocational Education***, 1982 (OC 83—$2.25).

Petty, Reginald. ***Trends and Issues in Vocational Education: Implications for Vocational Education Research and Development***, 1978 (OC 46—$1.90).

Pierce, William. ***Current and Emerging Structures for Education and Training: Implications for Vocational Education R&D***, 1980 (OC 68—$2.20).

Poulard, Othello W. ***The Expanding Role of Community-Based Organizations: Implications for Vocational Education***, 1983 (OC 90—$2.25).

Pucinski, Roman. ***The Role of State and Local Advisory Councils in Vocational Education***, 1978 (OC 36—$1.90).

Reider, Corinne H. ***Women, Work and Vocational Education***, 1977 (OC 26—$1.90).

Rumberger, Russell. ***Demystifying High Technology***, 1984 (OC 97—$2.50).

Schergens, Becky L. ***The Parent's Role in Career Development: Implications for Vocational Education Research and Development***, 1980 (OC 60—$1.90).

Schmidt, Hermann. ***Current Problems of Vocational Education in the Federal Republic of Germany***, 1979 (OC 54—$1.90).

Shannon, Thomas A. ***The Role of Local School Boards in the Development and Direction of Programs of Occupational Education***, 1980 (OC 58—$1.90).

Silberman, Harry F. ***Determining Goals for Vocational Education***. 1983 (OC 96—$2.75).

Steiner, Gerhard. ***Current Problems in Vocational Education in Switzerland: Report on a National Research Program***. 1983 (OC 93—$2.75).

Sticht, Thomas G. ***Literacy and Vocational Competence***, 1978 (OC 39—$2.80).

Striner, Herbert E. ***The Reindustrialization of the United States: Implications for Vocational Education Research and Development***, 1981 (OC 71—$2.20).

Sullivan, Dennis J. ***Improving Productivity in the Work Force: Implications for Research and Development in Vocational Education***, 1981 (OC 72—$2.35).

Super, Donald E. ***New Dimensions in Adult Vocational and Career Counseling***, 1985 (OC 106—$3.50).

Taylor, Daniel B. ***Revitalizing the American Economy: A Research and Development Focus for the 80s***, 1980 (OC 64—$1.90).

Tolbert, Jack F. ***The Role of Private Trade and Technical Schools in a Comprehensive Human Development System: Implications for Research and Development***, 1979 (OC 53—$1.90).

Tucker, Alvin. ***The Role of Education in National Defense***, 1982 (OC 86—$2.25).

Wallace, Bertran F. ***Desegregation and Its Implications for Vocational and Career Education***, 1977 (OC 30—$1.75).

Watkins, Wesley W. ***The Entrepreneurs of Entrepreneurship***, 1982 (OC 84—$2.25).

Wills, Joan. ***Youth Unemployment: Implications for Vocational Education R&D***, 1977 (OC 32—$1.75).

Wirth, Arthur G. ***Alternative Philosophies of Work: Implications for Vocational Educational Research and Development***, 1981 (OC 78—$1.90).

Wirtz, Willard R. and Ford, Gerald R. ***Bringing the World of Work and the Institutions of Education Closer Together***, 1977 (OC 28—$1.75).

Worthington, Robert M. ***Vocational Education in the United States: Retrospect and Prospect***, 1984 (OC 101—$3.00).

ORDERING INFORMATION

All prices include postage and handling. When ordering use series numbers and titles. Orders of $10.00 or less will be accepted on a cash, check, or money order basis only. Purchase orders will be accepted for orders in excess of $10.00. Please make check or money order payable to: **The National Center for Research in Vocational Education**. Mail remittance and/or purchase order to: National Center Publications, The Ohio State University, 1960 Kenny Road, Columbus, OH 43210. (Prices subject to change.)

The Lecture Series at the National Center for Research in Vocational Education was established to provide a forum for discussing current issues confronting educational research and development among distinguished professionals and National Center and Ohio State University staff. **Points of view or opinions do not necessarily represent official National Center or Ohio State University position or policy and no official endorsement of these materials should be inferred.**